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Performance of the AEDC Mark I Aerospace Environmental Chamber without Oil Diffusion Pumping

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Calspan Field Services, Inc.

February 1982

Final Report for Period 23 – 24 June 1981

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The 40- by 80-ft MK-I Aerospace Environmental Chamber was pumped down to a pressure of 2×10^{-6} torr in order to verify an operational mode that could maintain test conditions without the use of oil diffusion pumping. Mechanical pumps rough pumped into the micron (1 to 10.0 x 10^{-3} torr) range, and the cryogenic arrays reduced the pressure to 2×10^{-6} torr and maintained it for 24 hours. The pumpdown without the use of diffusion pumping is often dictated by test requirements for exceptional cleanliness. After

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pumpdown, inbleeding of CO_2, H_2, and N_2 affected chamber pressure as a function of gas species and inflow rate. The time for the liquid nitrogen and gaseous helium-cooled cryosurfaces to cool down and warm up was determined as an aid to test planning. Because several modifications to the cryopumping geometry had been made since the chamber was initially placed into service, it was considered important to verify the MK-I performance. It is concluded that the mechanical roughing/cryogenic pumping method of operation is satisfactory for simulation of conditions where the outgassing is relatively small or consists of gases with low vapor pressure at liquid nitrogen temperature (i.e., CO_2 or H_2O).

PREFACE

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force System Command (AFSC), at the request of the Defense Nuclear Agency. The results of the test were obtained in the von Kármán Gas Dynamics Facility by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee, under project number V91R-P1. This technical report was prepared under project number C097VR. The DNA task manager was Mr. Lawrence Ashbaugh, and the Air Force Project manager was Mr. A. E. Dietz, AEDC/DEVM. The data analysis was completed in July 1981, and the manuscript was submitted for publication on November 6, 1981.

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ILLUSTRATIONS

1.0 INTRODUCTION

The Mark I Aerospace Environmental Chamber at the Arnold Engineering Development Center is designed to simulate vacuum and thermal environments for development testing of space systems (Ref. 1). It is normally pumped down with rotary mechanical pumps, blowers, diffusion pumps, and liquid nitrogen and gaseous helium cryopumps. Some tests, such as those for infrared sensing systems, require a clean environment and have small gas-pumping requirements so that cryogenic pumping alone may be possible with the diffusion pumps valved off. The mode of pumpdown adopted for this evaluation involved evacuation of the chamber with the mechanical rotary pumps and blowers while simultaneously cooling the interior cryopanels with liquid nitrogen and gaseous helium from the 4-kw refrigerator. After a base pressure (1 to 10 μ Hg) was attained, the mechanical pumps were valved out and evacuation was continued entirely by the cryogenic surfaces. The objective of this investigation was to determine whether a chamber pressure of about 10^{-6} torr could be maintained with cryogenic pumps alone.

2.0 APPARATUS

The Mark I chamber is a stainless steel vessel 42 ft in diameter by 82 ft high. The chamber volume is approximately 104,000 ft^3 (3×10^6 liters). The chamber interior is lined with panels which are cooled by liquid nitrogen (LN_2) to a temperature of approximately 80 K. The clear space in the chamber prior to installation of any test hardware or test article is a relatively unobstructed cylindrical volume 34 ft in diameter by 60 ft high. Figure 1 is an outline of the chamber in this pumpdown configuration.

The vacuum pumping system normally used for achieving the simulated pressure altitude required for testing consists of mechanical vacuum pumps and blowers, oil diffusion pumps, and a gaseous helium cooled (20-K) cryopump. A schematic of the present configuration of the mechanical and diffusion pumping systems is shown in Fig. 2. The rough pumping system, used for evacuating the chamber from atmospheric pressure (750 torr) to approximately 10^{-2} torr, consists of two 850-cfm mechanical pumps (49MP1 and 49MP2), mechanical forepumps (48FP1 through 48FP18) and two 4000-cfm mechanical blowers (49MB1 and 49MB2). One of the mechanical forepumps (48FP12) is also used to evacuate the chamber LN_2 cryosystem during the pumpdown.

There are presently 19 diffusion pumps installed on the chamber, eight of which are operational with angle valves and LN_2-cooled baffles separating them from the chamber. The operational pumps, which attach to the chamber at the −24-ft elevation ("D" level), include 47DP1 and 47DP2, and 47DP7 through 47DP12. Four diffusion pumps with baffles

and angle valves (47DP3 through 47DP6) had previously been removed for use in another AEDC chamber. The "B" level diffusion pumps have not been required for Mark I test programs and are not currently operational.

The Mark I GHe cryopumping system originally consisted of six flow zones for nominally 20-K gaseous helium supplied by one or two 4-kw refrigeration units located in the Mark I refrigeration plant. The modified system is shown schematically in Fig. 3. The two currently active zones are H-144 and H-198, the numeral indicating the chamber azimuthal location of the center of the zones. The remaining four zones could be made active if a requirement existed. The helium from the plant to these zones has been diverted to other in-chamber uses for special test programs, such as the HI-V-3 background panel for out-of-field-of-view-rejection (OFVR) test programs indicated on the schematic in place of flow zone H-259.

A gas inbleed system connected to the bottom of the chamber allowed various gases to be introduced into the chamber from 1A cylinders with pressure regulators. Four Matheson 604 flowmeters and a Fisher-Porter flowmeter in parallel permitted introducing controlled flows of up to 3000 torr-liters/sec of N_2 or 12,000 torr-liters/sec of H_2.

The two active flow zones have been modified, as indicated in Fig. 3, by the removal of a portion of the pumping surfaces in the lower half of the chamber (the circled areas indicate modifications to the original system). The zones consist of 1-1/2 in.-diameter copper tubes which are radiation shielded by the LN_2 panels from the chamber interior and chamber exterior walls. There is presently over 1000 ft of tubing in the two flow zones, with a surface area of approximately 3×10^5 cm^2.

The liquid nitrogen circulation system is shown schematically in Fig. 4. Liquid nitrogen flow to the panels in the chamber is controllable in 21 separate zones by means of valves located in the supply and return lines just exterior to the chamber. Approximately 50 percent of the liquid nitrogen surface in the chamber was cooled during this demonstration pumpdown. As indicated on the schematic, the wall zones between chamber azimuth locations of 84 and 228 deg (LN 84 and LN 228, respectively) were actively cooled, as was the chamber floor (LN-FHS). The "D" level diffusion pump baffles and lower "scavenger" panel were cooled by a separate LN_2-circulating system.

The wall panels not actively cooled, the zones around 36 and 300 deg, which were valved off from LN_2 circulation, received some cooling by radiation to the cold zones and also by means of a small amount of leakage through the isolation valves. Schematics of the LN_2 and GHe circulation systems are shown in Figs. 5, 6, and 7.

3.0 TEST DESCRIPTION

Prior to the start of the pumpdown, the GHe and LN_2 cryosystems in the chamber were evacuated with vacuum pumps. This panel evacuation, normally to a pressure of less than 1 torr, was continued during the chamber pumpdown for the purpose of evaluating the cryosystem leakage into the chamber. The pre-operation checkouts of the refrigeration plant equipment and the vacuum pumping system were conducted prior to the start of chamber evacuation. The GHe refrigeration system was operated on a chamber cryosystem bypass circuit for approximately 16 hours prior to the time it was needed for cyrosystem cooldown.

The pumpdown was started by opening a single vacuum valve which isolates the chamber interior from the mechanical vacuum pumps. The vacuum pumping speed of the chamber between atmospheric pressure and 10 torr is approximately 3500 cfm. This includes the two 850-cfm roughing pumps and 17 smaller (average of 100 cfm) mechanical pumps. At the 10-torr pressure level, the two 4000-cfm blowers are started and the 850-cfm roughing pumps are used to back the blowers. The smaller mechanical pumps are normally isolated from the chamber at 1 torr and used as forepumps to back the oil diffusion pumps. Since the diffusion pumps were not operated during the chamber evacuation, these pumps were not isolated from the chamber until a pressure level of approximately 3.5×10^{-2} torr was reached, which is nearly the base pressure of the pumps.

The variation in chamber pressure as a function of time from the start of the pumpdown to a pressure level of 2×10^{-2} torr is shown in Fig. 8. Included in the figure is a theoretical pumpdown curve based on chamber volume and pumping speed through the formula

$$T = (V/S) \ln (P_1/P_2)$$

where T is the time in minutes (Ref. 2) required to evacuate the 104,000-ft^3 Mark I chamber from some initial pressure P_1 to a level P_2 and S is the vacuum pumping speed, approximately 3500 cfm from atmosphere to 10 torr and 8000 cfm below 10 torr.

Deviations from the theoretical curve are normally caused by leakage into the chamber or outgassing of materials in the chamber. Approximately one hour after the start of the demonstration pumpdown a large leak was located in a chamber penetration. This leak was neutralized for the remainder of the pumpdown, but it delayed chamber evacuation approximately 20 minutes. When the chamber pressure falls below 1 torr, water vapor outgassing from the interior chamber surface is the normal cause of pressure deviation from the theoretical values. In order to reduce this effect a "scavenger" panel was cooled with LN_2 when the chamber pressure reached 1 torr. This panel provides a higher pumping speed for water vapor than is provided by the mechanical pumps and blowers and also reduces the amount of water in the oil in the mechanical pumps, thus improving the pump base pressure.

A chamber pressure of 2×10^{-2} torr was reached approximately five hours after the start of the pumpdown. At this time the mechanical pumping system was isolated from the chamber and a "rate-of-rise" evaluation was made of the chamber leakage. During a 10-minute period there was no discernable pressure increase in the chamber. The minimum increase that could have been noted with the chamber pressure instrumentation was approximately 1×10^{-4} torr. The chamber leakage was therefore less than

$$(1 \times 10^{-4}/600) \times 3 \times 10^{6} = 5 \times 10^{-1} \text{ torr } \ell/\text{sec}$$

$$(\text{Pressure Rate-of-Rise} \times \text{Chamber Volume}) = (\text{Leak Rate})$$

Next, the leakage into the chamber from the ambient temperature LN_2 cryosystem was evaluated by the same method. The panels, which had been evacuated internally to a pressure of less than 1 torr, were pressurized to a pressure of 28 psig. During a 10-minute period following this pressurization the chamber pressure rose from 8.8×10^{-3} torr to 9.6×10^{-3} torr. The cryosystem plus chamber leakage was therefore

$$(0.8 \times 10^{-3}/600) \times 3 \times 10^{6} \approx 4 \text{ torr } \ell/\text{sec}$$

This leakage was primarily nitrogen from the cryopanels and chamber wall air leaks which would also include a small amount of oxygen. These gases are both condensable in the cryopump temperature range from 20 to 30 K. The pumping speed of a 20-K surface for gases condensable at this temperature over the pressure range from 10^{-3} to 10^{-7} torr is approximately 10 ℓ/sec (± 50 percent) (Ref. 2) per square centimeter of cold surface. The total cryopumping speed was therefore

$$3 \times 10^{5} \text{ cm}^2 \times 10 \ \ell/\text{sec-cm}^2 = 3 \times 10^{6} \ \ell/\text{sec}$$

The chamber base pressure expected when the cryopump was cooled was

$$(4 \text{ torr } \ell/\text{sec})/3 \times 10^{6} \ \ell/\text{sec} \approx 1.3 \times 10^{-6} \text{ torr}$$

$$(\text{Leak Rate Throughput/Pumping Speed}) = (\text{Pressure})$$

Since this was the pressure range desired for the test, cooldown of the LN_2 and GHe systems was initiated.

The allowable leakage rate from the GHe system is much less than that from the LN_2 system or that from the atmosphere since the helium is noncondensable and can be pumped from the chamber only with the diffusion pumps. The allowable leakage was taken to be the rate that would raise the chamber pressure from 1×10^{-6} torr to 1×10^{-5} torr in a 24-hour period.

This rate is

$$(9 \times 10^{-6}\ \text{torr})/[24\ (3600)\ \text{sec}] \times 3 \times 10^{6}\ \ell \approx 3 \times 10^{-4}\ \text{torr}\ \ell/\text{sec (He)}$$

This rate is too small to be determined by the "rate-of-rise" method. Therefore, a helium mass spectrometer leak detector is attached to the chamber to sample the volume when the GHe panels are pressurized. There was no discernable leakage from the warm GHe panels. A leakage rate of 1×10^{-5} torr ℓ/sec is readily observable with this evaluation method.

The cooldown of the LN_2 panels was started following the leakage evaluation (Fig. 9). Approximately 30 minutes later the cooldown of the GHe system was started. The cooldown of the LN_2 system usually takes between six and ten hours. The cooldown rate is controlled by the refrigeration plant operators. Due to recent increases (primarily electrical) in the cost of operating the reliquefication system, the cost of losing the boil-off gas is becoming comparable to the reliquefication costs, and this cooldown rate restriction is somewhat relaxed. The boil-off rate was also reduced since only 50 percent of the cryosystem mass was cooled. The cooldown time of the LN_2 cryosystem during this pumpdown was less than four hours.

The GHe flow from the cryopump to the refrigerator is precooled to LN_2 temperature in a heat exchanger during the initial part of the cryopump cooldown (from ambient to 90 K). The heat exchanger is then bypassed, and the plant refrigeration system is used to continue the cooldown. Figure 9 shows the average LN_2 and GHe panel temperatures during the cooldown and hold period of the pumpdown. The LN_2 temperatures shown are outlet temperatures and lag the actual panel temperature considerably. The GHe cryopump temperature was reduced to approximately 36 K after 3-1/2 hours of gaseous helium flow. At this temperature, cryopumping of the nitrogen in the chamber started.

Shortly over four hours after the start of the pumpdown, the mechanical pumping system was isolated from the chamber as the chamber pressure began to drop due to cryopumping. Ten hours after the start of the pumpdown the chamber pressure reached 2×10^{-6} torr at a cryopump temperature of approximately 27 K. The pressure dropped to 1.4×10^{-6} torr when the cryopump temperature stabilized near 20 K. The chamber pressure was then constant (within gage accuracy) for the twelve-hour isolation period (Fig. 9). Figure 10 summarizes cooldown and warmup of the cryogenic systems during the entire test period.

Following a brief evaluation of pumping speeds, discussed in Section 4.0, the cryosystems were warmed back to ambient levels (280 K) and the chamber was returned to atmospheric pressure. The LN_2 cryosystem warmup was started by cutting off the LN_2 flow to the panels and pressurizing the Mark I chamber to approximately 5×10^{-1} torr. The

panels were then warmed by convection from the chamber exterior wall. Active heating of the LN_2 panels by circulation of warm N_2 through the flow passages was started after about 1-1/2 hours. This gas flow is supplied by the nitrogen reliquefaction compressor. By eight hours' time the average cryopanel temperature was raised to above 270 K; chamber repressurization with atmospheric air required about one hour and 40 minutes longer.

4.0 RESULTS

The pumping speeds of the chamber vacuum and cryopumping systems were also demonstrated during the pumpdown by introducing fixed rates of flow of various gases into the chamber through the flowmeters. The gases flowed in were carbon dioxide, which condenses on LN_2-cooled surfaces, nitrogen, which condenses in the GHe cryopump, and hydrogen, which must be removed from the chamber by the diffusion pumps, eight of which were used. Figure 11 shows how the chamber pressure varies with gas inbleed (throughput) rate for these three gases. The pressure levels plotted were measured with an ionization gage located in the top of the chamber; the gases were introduced into the bottom of the chamber.

The carbon dioxide condensed on the large area of LN_2-cooled surface with an almost negligible rise in chamber pressure. Inbleed rates of up to 200 torr ℓ/sec were introduced with indicated rise in chamber pressure from 1.8×10^{-6} to 2.1×10^{-6} torr. Water vapor also condenses on the LN_2 surfaces, and similar small pressure changes would be expected with water vapor inbleed instead of CO_2.

Nitrogen is a normal gas load in the chamber and usually is the gas limiting the achievable base pressure, since it results from either LN_2 cryosystem or atmospheric leakage. The chamber base pressure during the demonstration pumpdown was limited to approximately 1.5×10^{-6} torr due to a nitrogen leak rate of about 4 torr ℓ/sec. Much higher levels were introduced for the pumping speed evaluation. The higher levels would be expected to be generated only during plume test programs conducted in the Mark I chamber. Figures 11 and 12 show the results of the nitrogen pumping speed evaluation. Thruput rates of up to 5000 torr ℓ/sec were pumped with the chamber pressure maintained below 1×10^{-3} torr. Flow rates of nearly 50 torr ℓ/sec could be pumped without exceeding a chamber pressure of 1×10^{-5} torr, a limiting pressure for satellite testing. The maximum N_2 flow rate results in a heat load of nearly 3 kw to the GHe refrigeration system. As indicated in Fig. 12, the cryopump temperature was maintained below 30 K for all N_2 flow rates. The arrows in Fig. 12 to the left of the pressure-time curve show when the flow was started.

Figure 13 shows the same type of data for inbleeding hydrogen. The pumping is primarily by the eight diffusion pumps, but the slower rise to equilibrium than for N_2

inbleeds may be indicative of some sorption of H_2 by the CO_2 frost on the LN_2 surfaces. Hydrogen is not a normal gas load in the chamber, again resulting in relatively large rates only during chamber plume test programs. However, hydrogen can be removed from the chamber only with diffusion pumps at approximately the same rate at which helium can be pumped. Helium gas loads result from GHe cryopump leakage, and, if this leakage should be substantial, diffusion pumps would be required to remove it from the chamber.

A maximum cryopump temperature rise of about 5 K was indicated during the hydrogen inbleed period. This heat flux resulted from increased convective heat loads between the 80-K LN_2 and the 20-K GHe cryopumps as the chamber pressure rose with inbleed rates.

5.0 CONCLUSIONS

The following conclusions can be drawn from the results of the demonstration pumpdown:

1. A base pressure less than 1×10^{-5} torr can be achieved in the Mark-I chamber and maintained for extended time periods without the use of diffusion pumping.
2. The time to reach the base pressure without diffusion pumps will be from 8 to 12 hours.
3. A base pressure of less than 1×10^{-6} torr can be achieved if nitrogen inleakage is less than 4 torr ℓ/sec.
4. A chamber pressure below 1×10^{-5} torr can be maintained in the presence of inbleed rates less than 1 torr ℓ/sec of H_2 or 70 torr ℓ/sec of N_2.
5. Inbleed rates of CO_2, and presumably of H_2O, less than 200 torr-ℓ/sec, cause no significant change in chamber pressure.
6. The time required to return the chamber to ambient conditions following completion of testing will be between 8 and 12 hours.

REFERENCES

1. *Test Facilities Handbook* (Eleventh Edition. "von Kármán Gas Dynamics Facility, Vol. 3." Arnold Engineering Development Center, April 1981.

2. Guthrie, A. and Wakerling, R. K., eds. *Vacuum Equipment and Techniques*, McGraw-Hill, 1949.

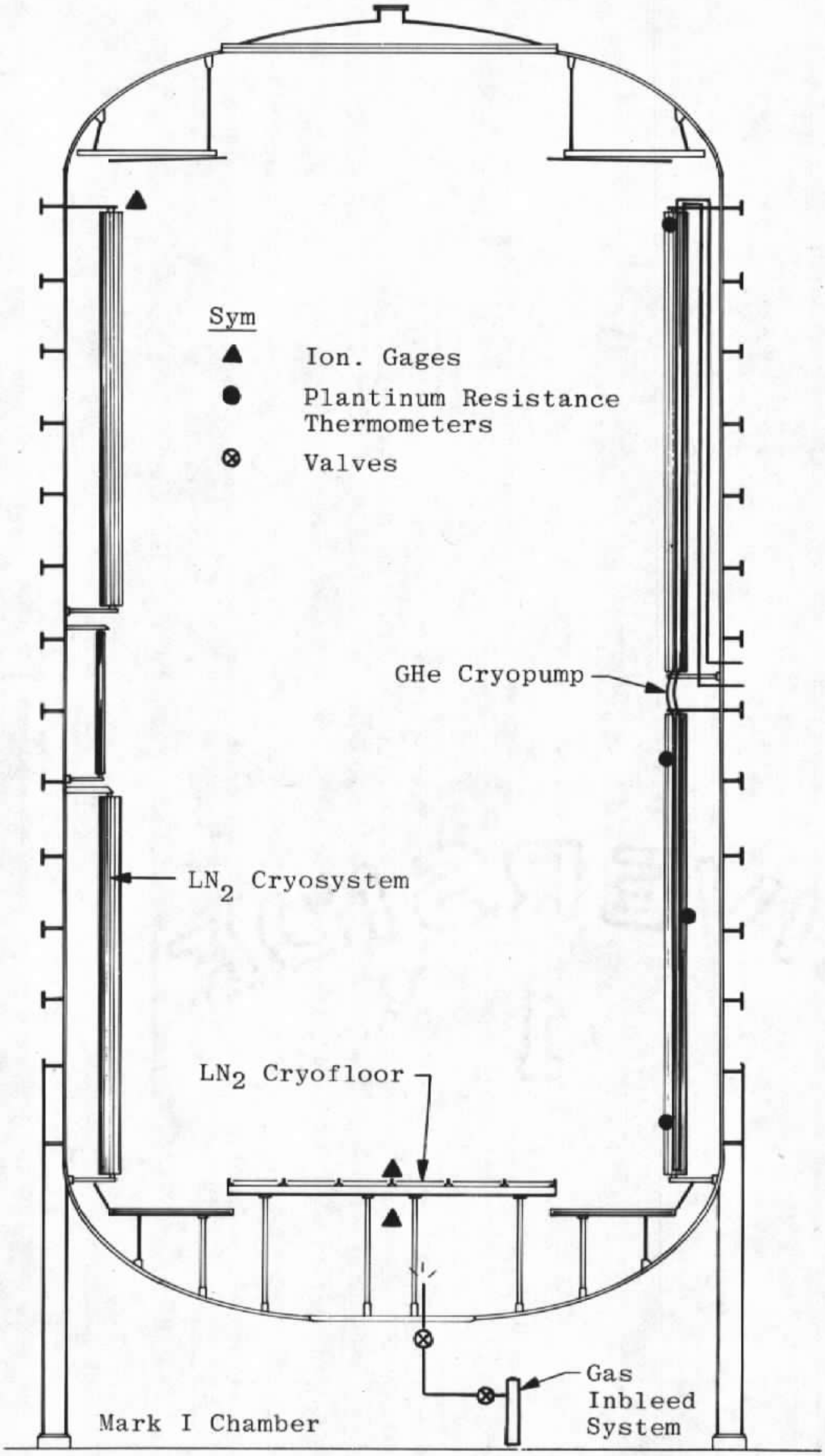

Figure 1. Pumpdown configuration.

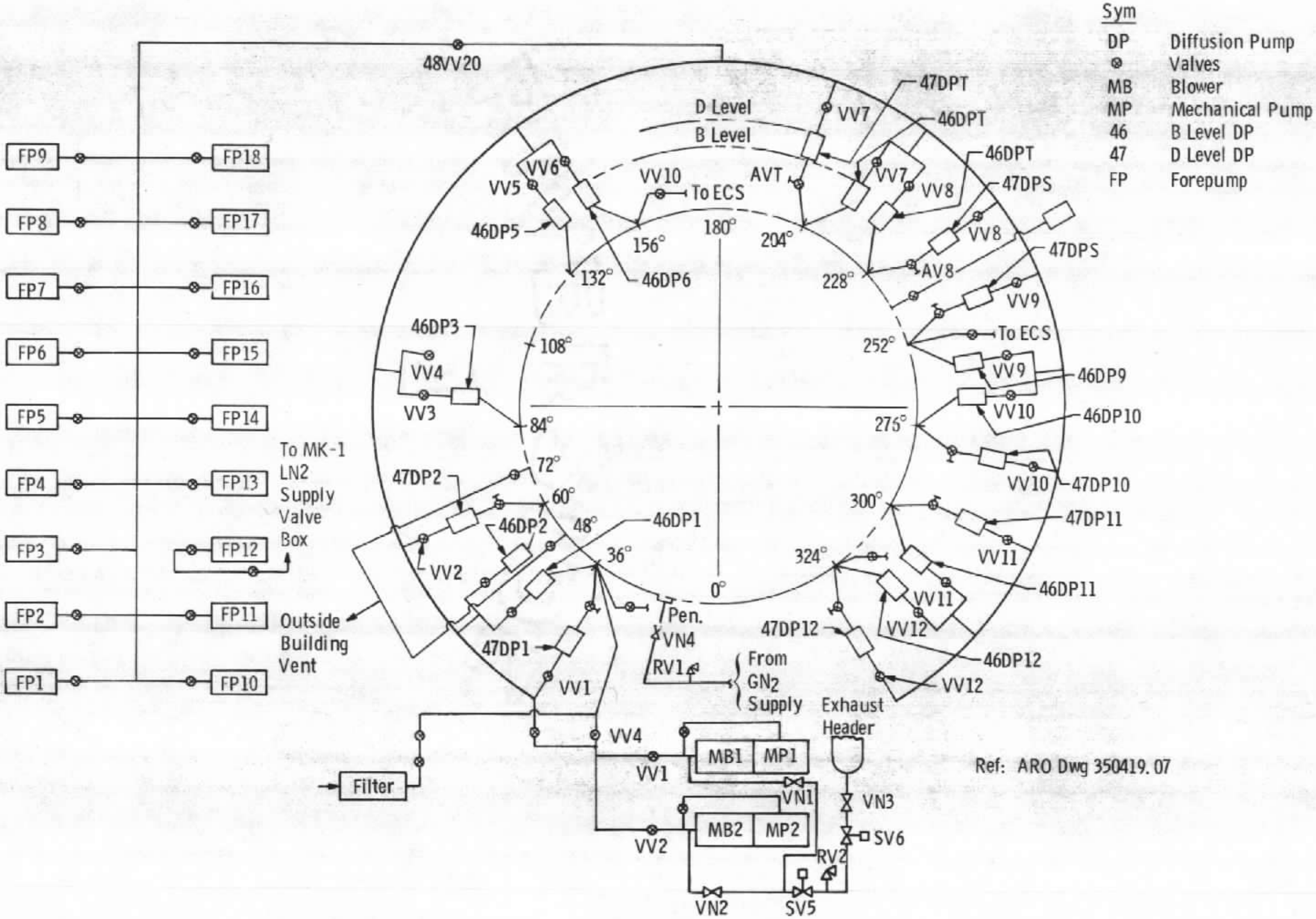

Figure 2. Mark I pumping system.

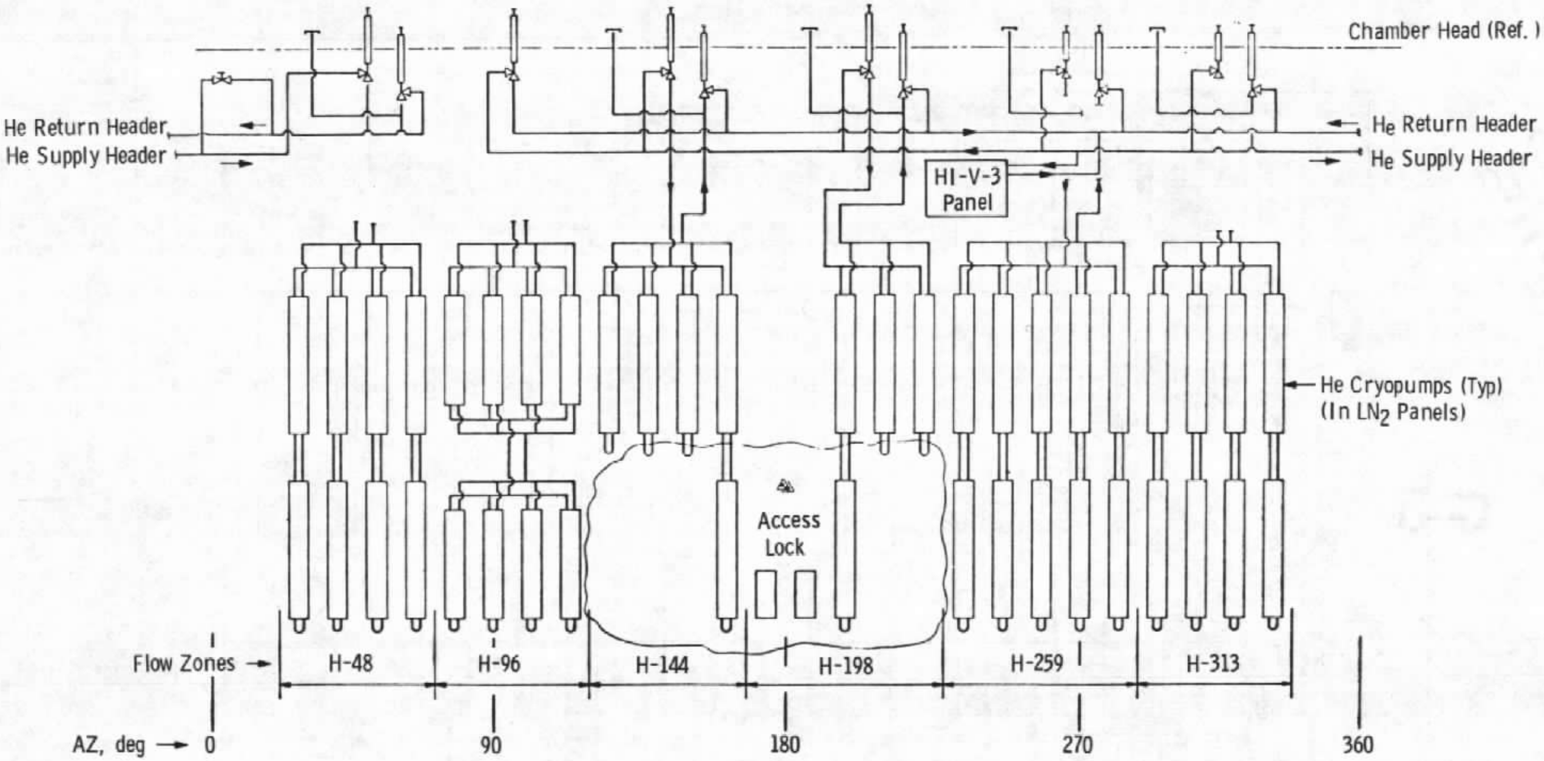

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Figure 3. Mark I 20-K GHe system.

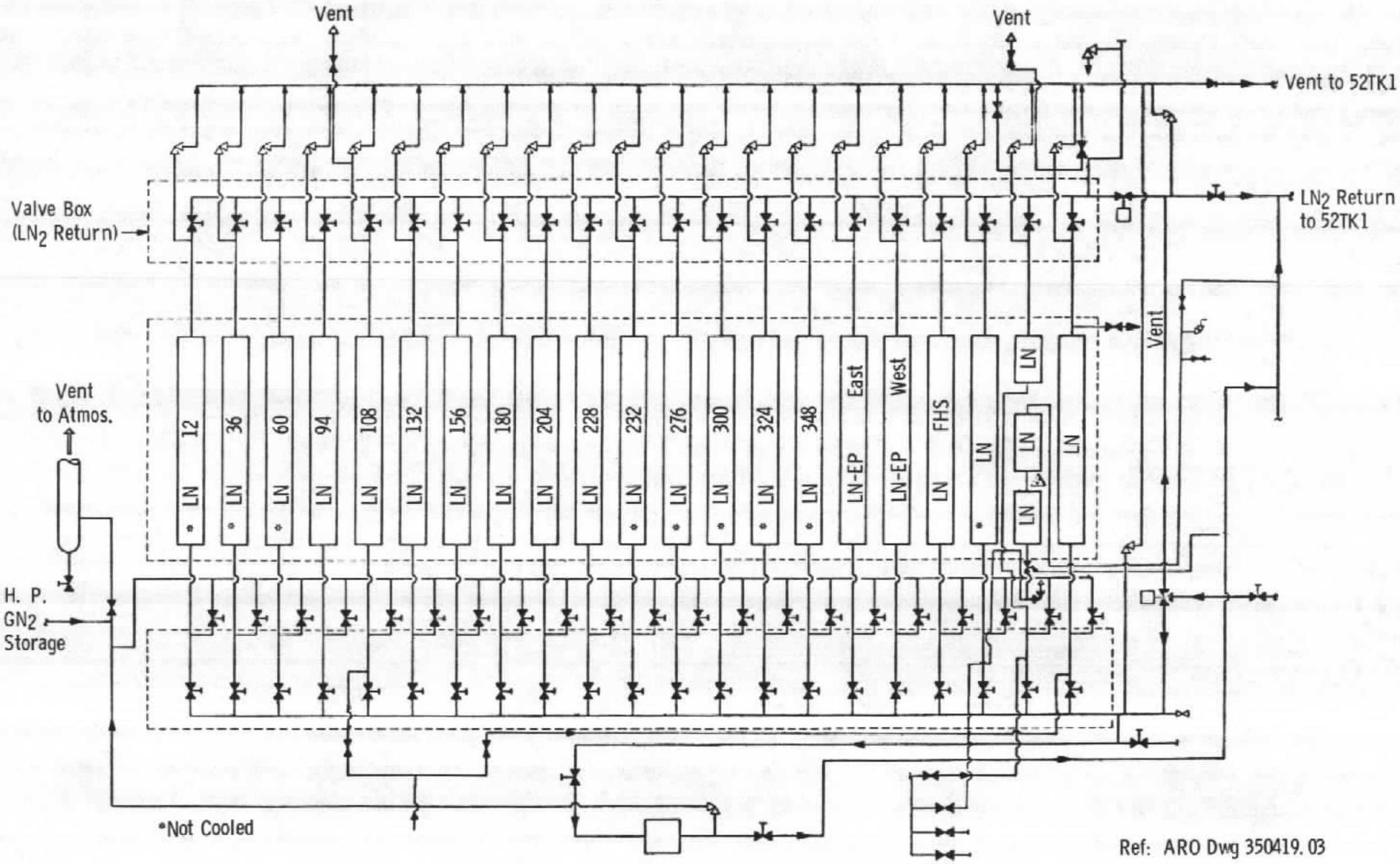

Figure 4. Mark I LN_2 system.

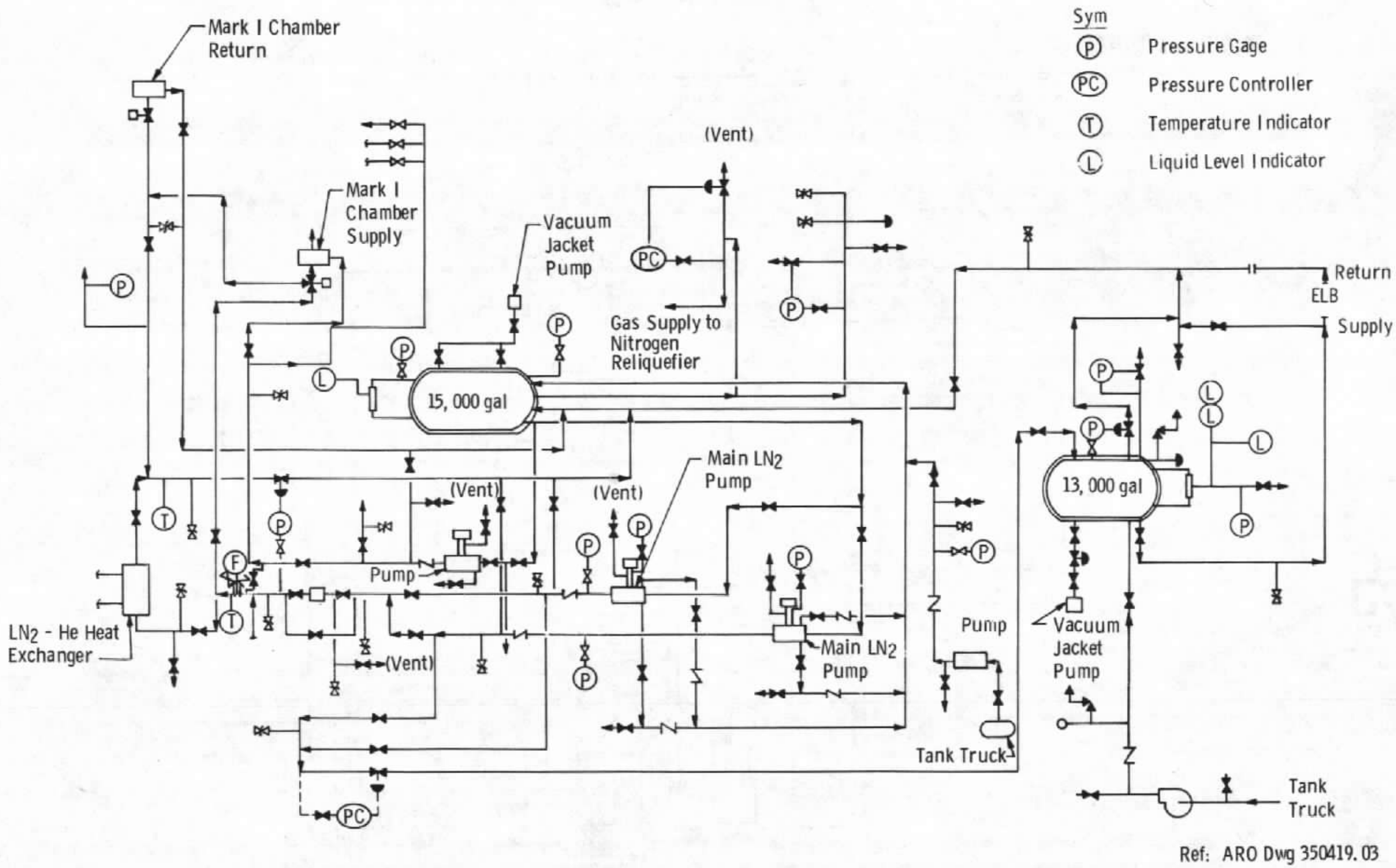

Figure 5. Plant LN_2 system.

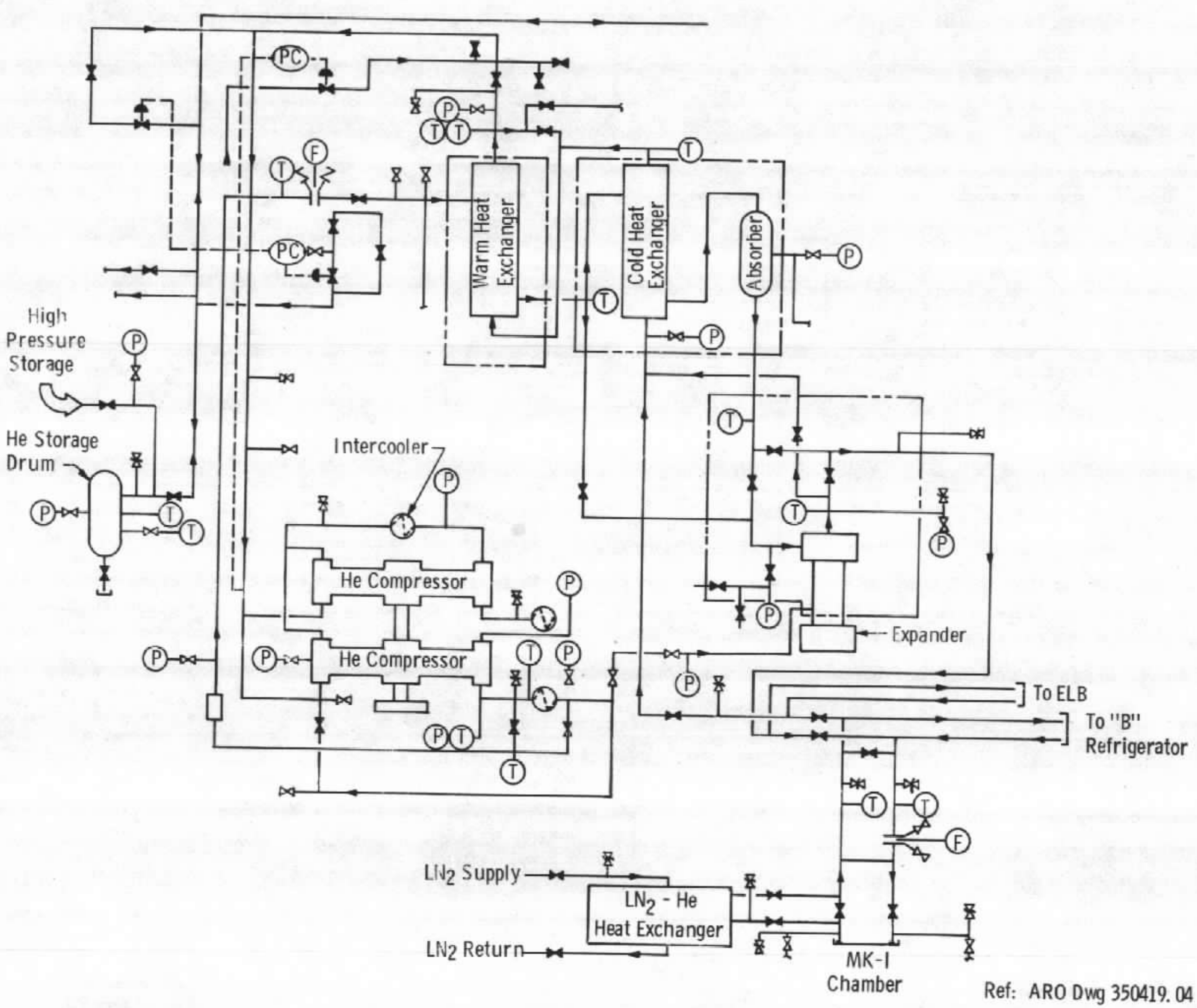

Figure 6. Plant 20-K GHe system.

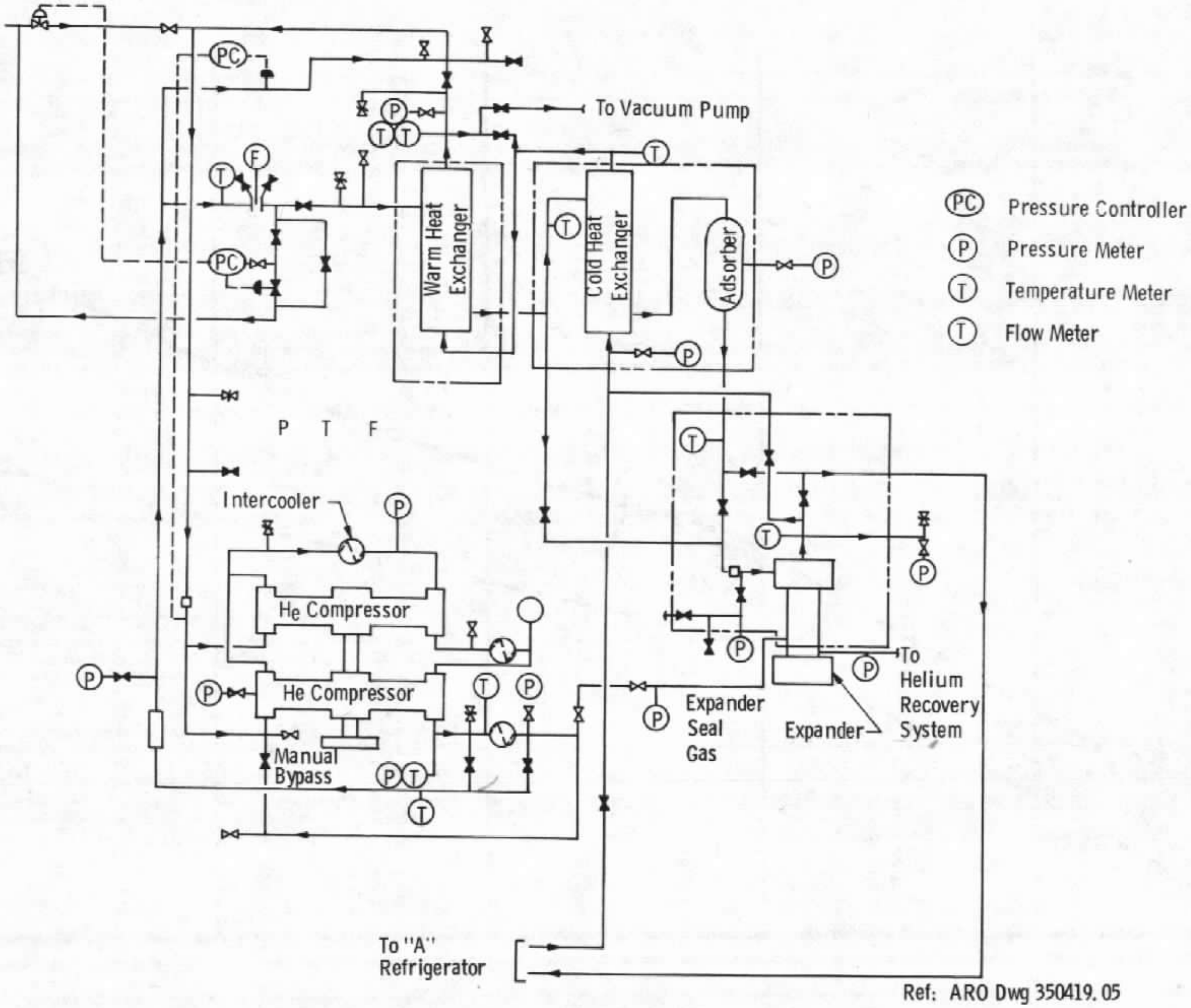

Figure 7. Schematic of helium refrigeration system.

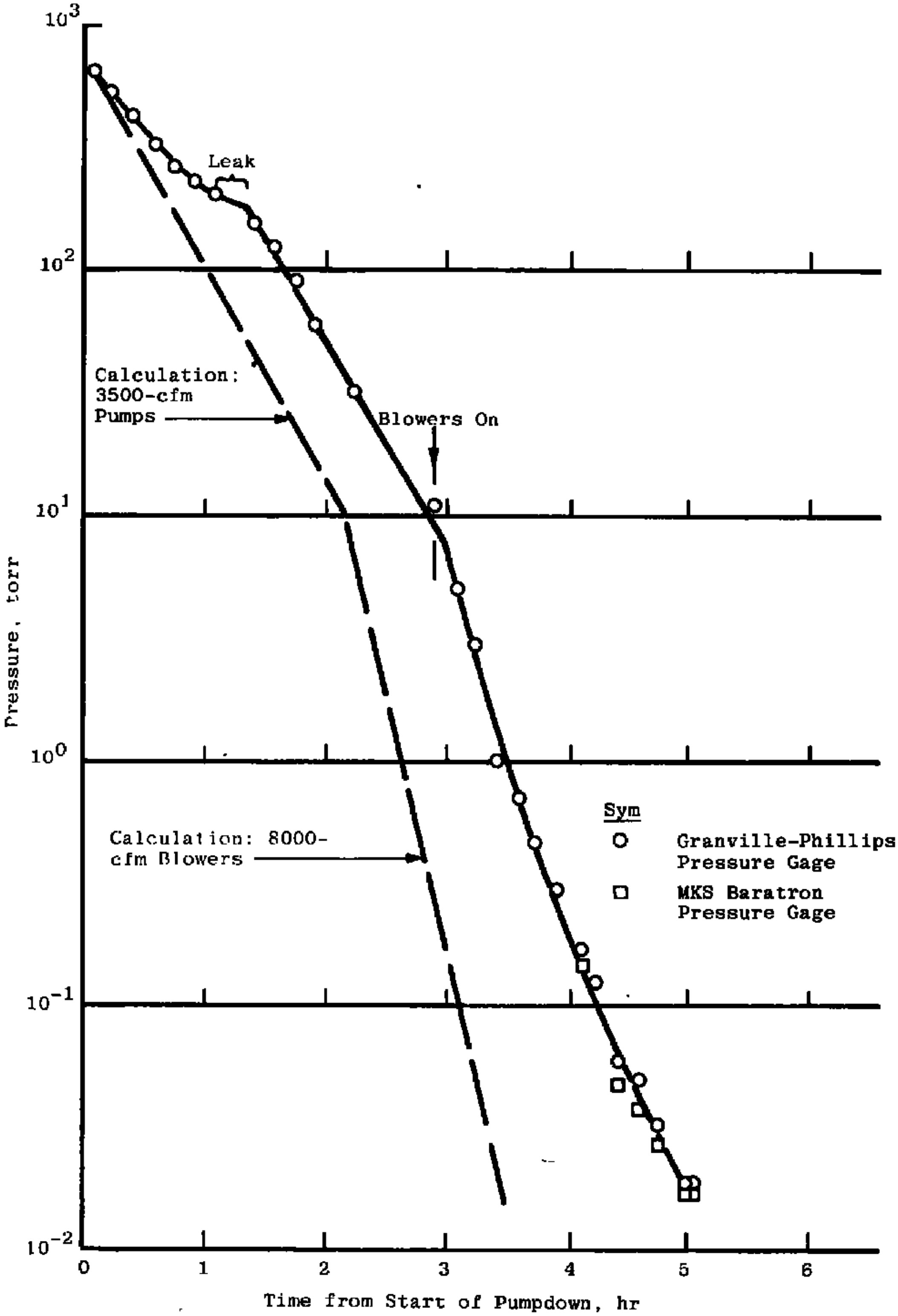

Figure 8. Mark I chamber rough pumpdown.

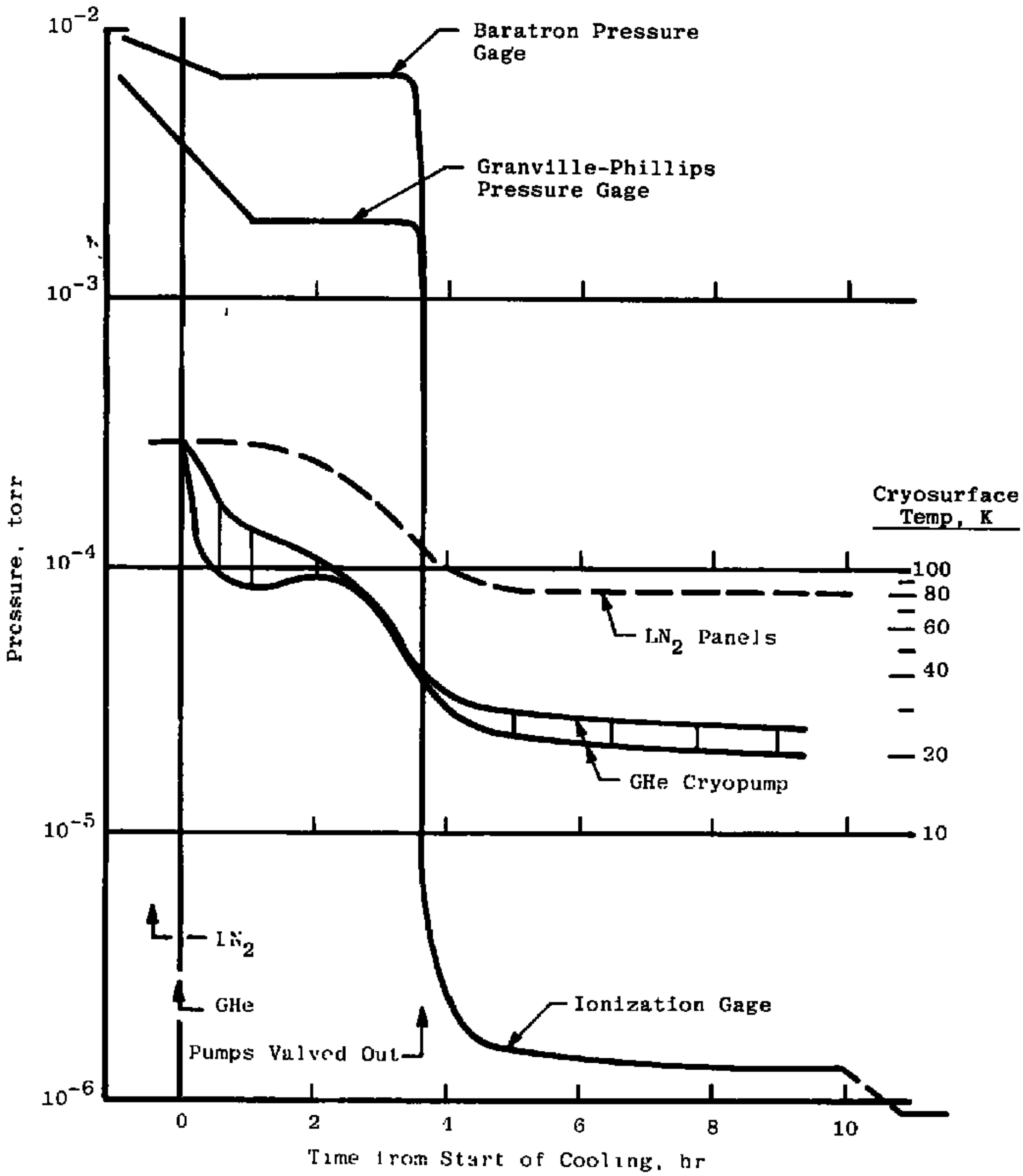

Figure 9. Mark I chamber cooldown.

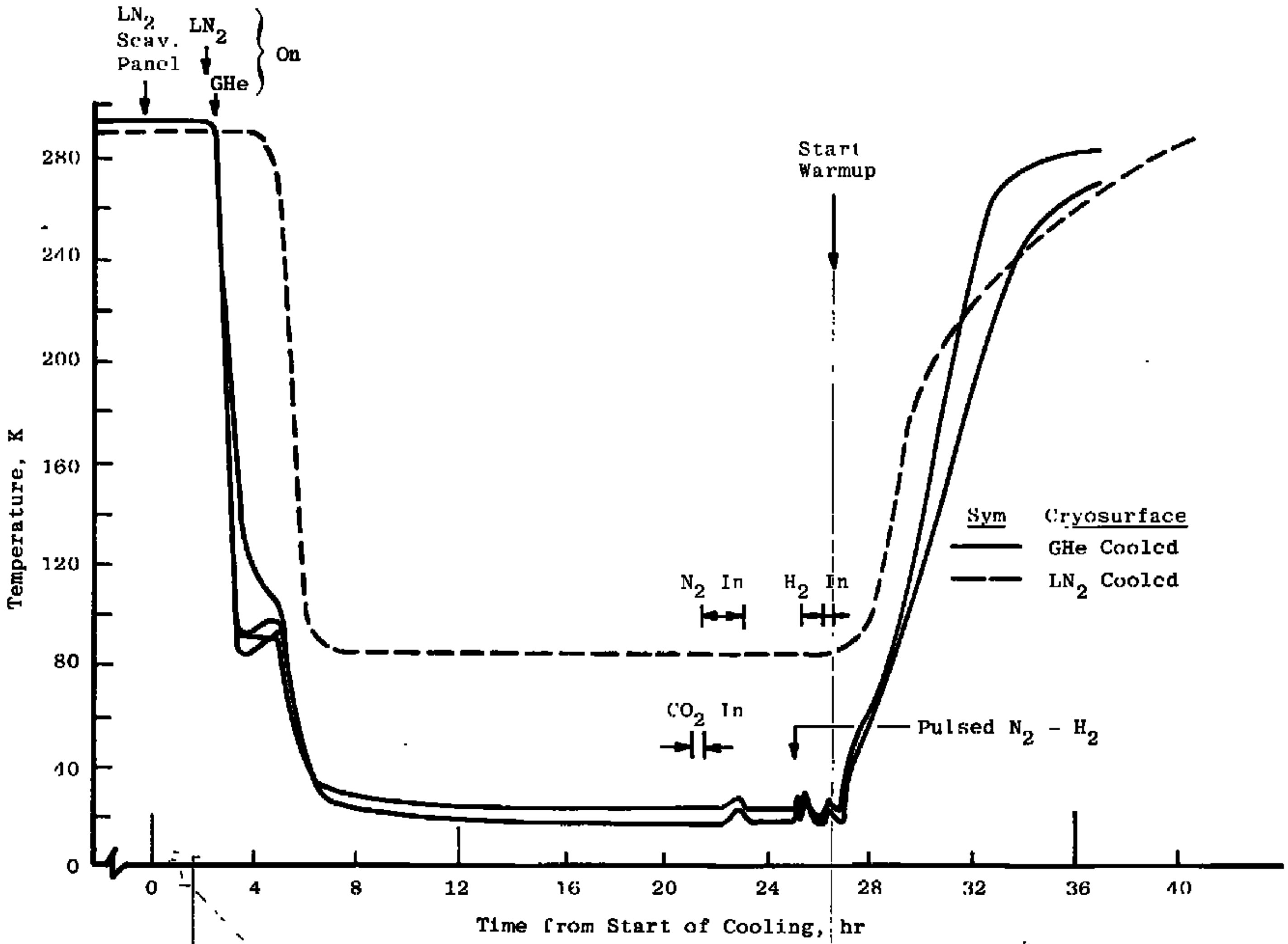

Figure 10. Mark I chamber cryogenic performance.

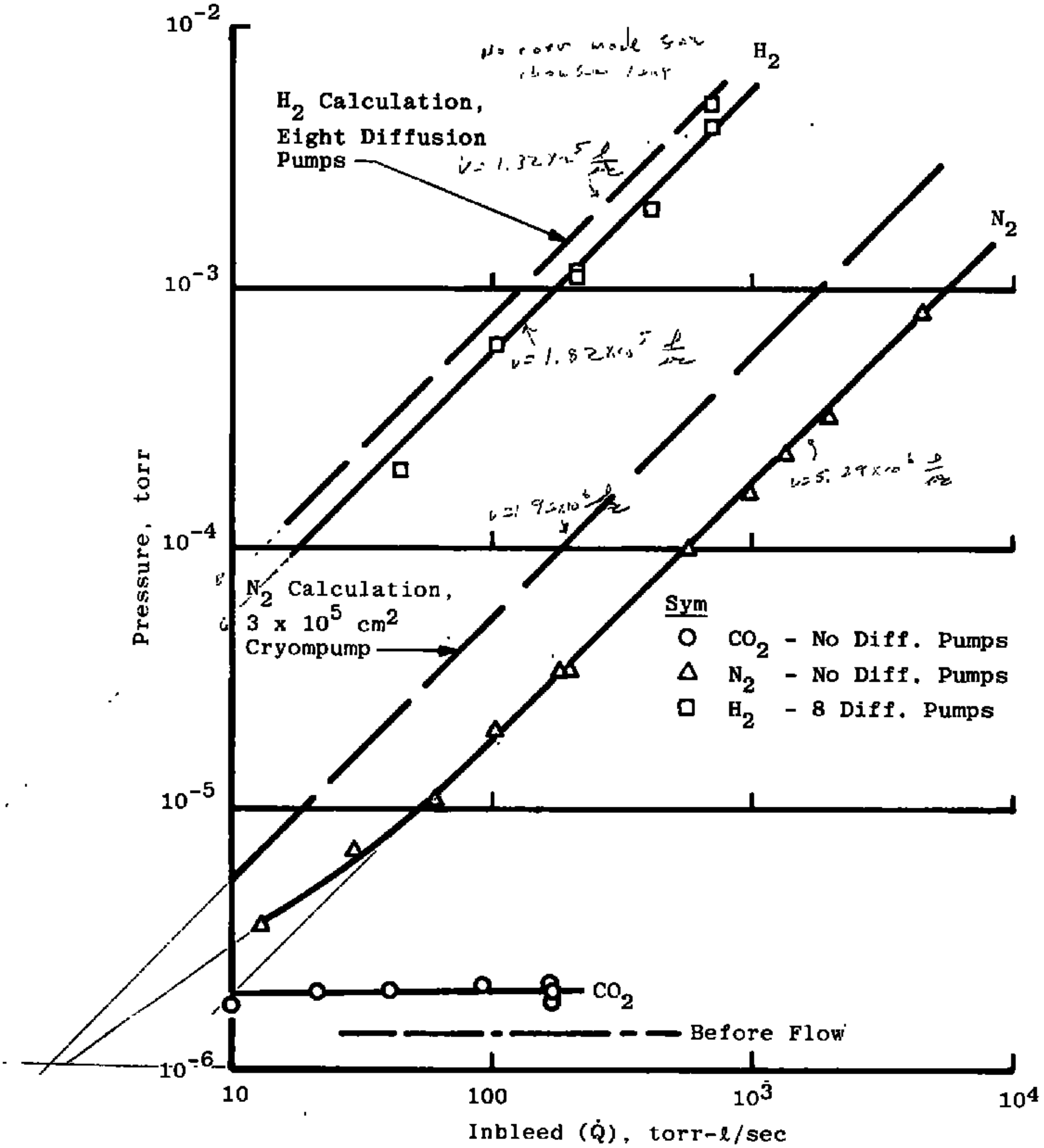

Figure 11. Mark I chamber pressure versus inbleed.

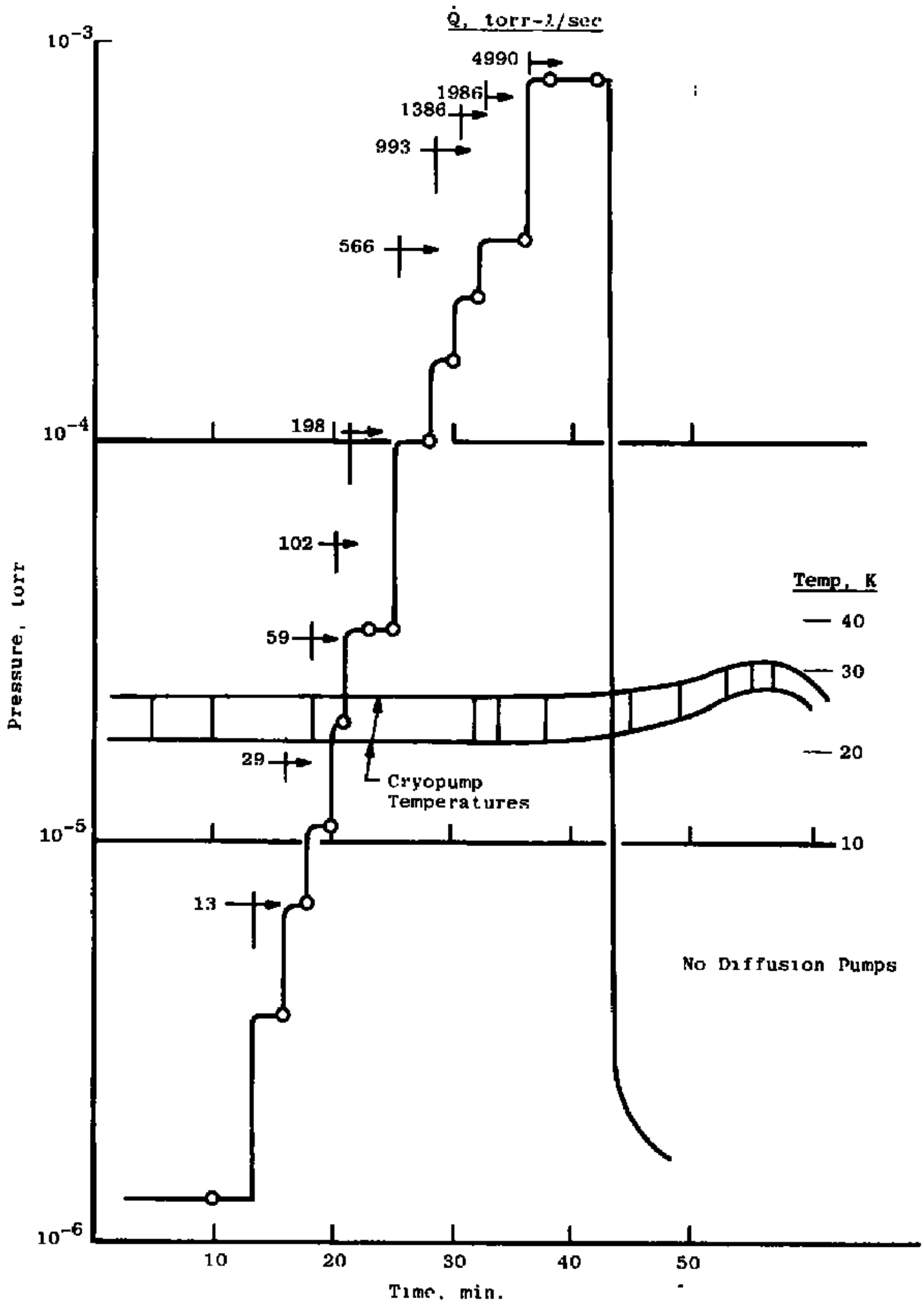

Figure 12. N_2 Inbleed to Mark I chamber.

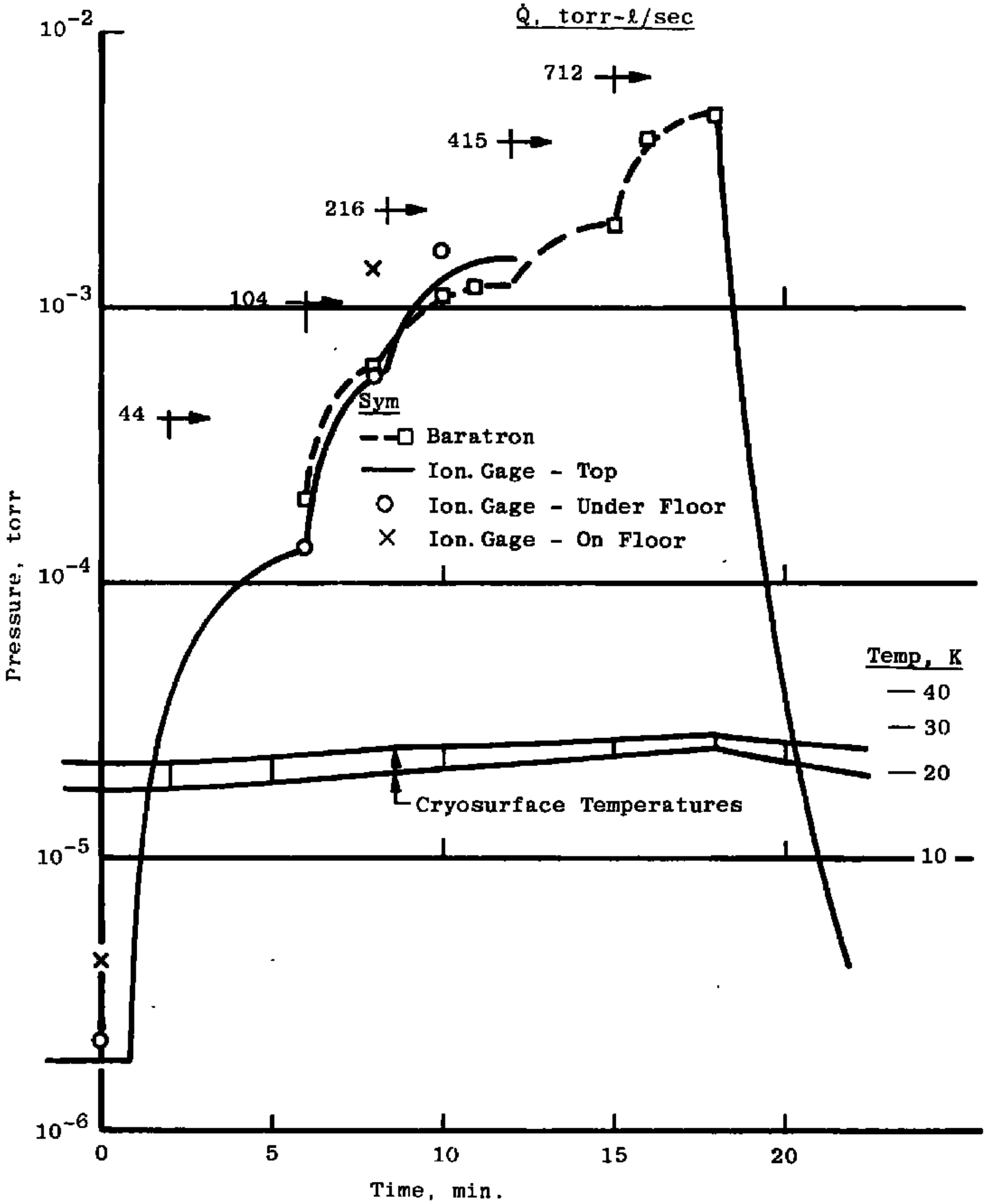

Figure 13. H_2 inbleed to Mark I chamber.